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Research article

# Soil properties and nutrient uptake of maize (*Zea mays*) as influenced by mixed manure and blended inorganic fertilizer in Haramaya district, eastern Ethiopia

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A R T I C L E I N F O

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A B S T R A C T

The deteriorating state of soil fertility and low agricultural productivity in Ethiopia can be traced to the lack of equivalent consideration given to the soil's biological, chemical, and physical properties. A pot experiment was conducted to investigate the effect of mixed manure and blended nitrogen, phosphorus, sulfur and boron (NPSB) fertilizer on phosphorus adsorption, and other properties of Vertisols, nutrient uptake, and growth performance of maize. The study findings indicate that the combined application of mixed manure and blended NPSB significantly reduced soil pH from 7.87 to 7.68, phosphorus adsorption efficiency from 93 to 88.5 %, and Freundlich adsorption capacity from 194 to 100.75 mg $kg^{-1}$ , intensity from 1.96 to 1.27 compared to control. However, combined application of these two treatments significantly increased the organic carbon from 0.81 to 1.64 %, total nitrogen from 0.04 to 0.13 %, and available phosphorus from 6.96 to 73.82 g $kg^{-1}$. The study further revealed that mixed manure and blended NPSB resulted in significantly ($p \leq 0.05$) higher contents of nitrogen and phosphorus in the maize leaves as well as their uptake compared to their sole application and control. The highest values of these parameters were observed in plots treated with a combined application of 15 t $ha^{-1}$ mixed manure with each rate of 100 and 150 kg $ha^{-1}$ blended NPSB. Additionally, the maize plant height ($p \leq 0.05$) and above-ground biomass ($p \leq 0.01$) also exhibited significant increase. Compared to the control and full dose of NPSB, all the treatments that received a combined application of 15 t $ha^{-1}$ mixed manure with blended NPSB ranging from 50 to 150 kg $ha^{-1}$ resulted in significantly higher above-ground biomass of maize. The results suggest that the combined use of mixed manure and blended NPSB could be a practical and effective approach to improve soil properties and maize above-ground biomass yield.

## 1. Introduction

The depletion of soil fertility has emerged as a critical biophysical factor contributing to the decline in per-capita food production in sub-Saharan Africa [1–4]. Particularly, in Ethiopia where the economy of the country primarily relies on agriculture, agricultural practices are characterized by low productivity, extensive nutrient mining, low use of external inputs, conventional farm management techniques, and a limited ability to adapt to environmental shocks [5,6]. Insufficient application of fertilizer and poor soil management

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practices, along with changing climatic conditions and associated factors have aggravated the decline of soil fertility and productivity [7–9]. This soil fertility decline has repeatedly been reported as the major constraint in agricultural production and food security [10,11]. Studies have shown that agricultural production is greatly limited by deficiencies in both secondary and micronutrients, as well as macronutrients [12–14]. In addition, the efficiency of fertilization is reduced by adsorption processes and precipitation, which are believed to be the main drivers of phosphorus unavailability to plants [15]. As a result, plants can utilize only a meager proportion, less than 25 %, of the applied phosphorus [16–18].

Furthermore, the high P-fixing properties of Vertisols, as well as their lack of crop response to P fertilization exacerbate productivity issues in Ethiopia [19]. Particularly, the Vertisols of the target study area have slightly alkaline to alkaline reactions due to the high contents of calcium carbonate, exchangeable calcium ($Ca^{2+}$), and magnesium ($Mg^{2+}$) in the soil [20,21]. The soils with such alkaline reactions containing high calcium and magnesium carbonates ($CaCO_3$ and $MgCO_{3,}$ respectively) can adsorb more P on their surfaces and provide $Ca^{2+}$ and $Mg^{2+}$ for precipitation reactions [22,23]. All these factors increase P fixation and make it a major yield-limiting factor for plant growth [24,25]. Furthermore, organic carbon (OC) content, which is an important indicator of soil health, was found to be low [26]. Such a low amount of soil OC in Vertisols constitutes one of the primary reasons for soil health loss, resulting in poor and unsustainable crop output [13,27]. Moreover, poor drainage and difficult workability limit nutrient availability and production, necessitating effective soil fertility and water management strategies. These phenomena underscore the need for exploring alternative approaches to optimize soil fertility and productivity.

The application of inorganic fertilizers containing blended nitrogen, phosphorus, sulfur and boron (NPSB) is considered as an important means to improve soil fertility and productivity. However, studies have shown a limit to which inorganic fertilizer alone can sustain the productivity of intensely cultivated soil. One of those limiting factors is the increasing cost of inorganic fertilizers, which could not consider the purchasing capacity of the farmers [28,29]. For example, in Ethiopia, most farmers have been applying less than 45 kg $ha^{-1}$ of inorganic fertilizer in crop production which is considerably less than the quantity required [30,31]. On the other hand, the continuous use of inorganic fertilizers alone causes the degradation of soil's chemical, physical, and biological properties, ultimately resulting in poor soil health [32–34]. For instance, the widespread use of ammonium-based N fertilizers can exacerbate soil acidification in soils with a lower pH [35,36]. Furthermore, frequent use of inorganic fertilizers alone can degrade the soil's organic matter and affect its structure, which can negatively impact water and nutrient retention [31]. Poor soil structure can significantly impede root growth, restricting the efficient utilization of nutrients and water by plants [32]. Therefore, to ensure optimal and sustainable soil use, an integrated management system that takes into account the biological, chemical, and physical components of soil fertility is necessary [8,33,34].

The application of organic materials to the soil is fundamental for enhancing soil physical, chemical, and biological fertility and productivity, which are key indicators of soil health [37,38]. Composted organic residues like manure are good organic fertilizers because of their balanced nutrient content as well as organic carbon, improve nutrients and water holding capacity of the soil, and also help the soil to maintain good tilth for better aeration, seed germination, and plant root development [39,40]. Moreover, organic residues can supply both macro and micronutrients to crops thereby reducing the cost of inorganic fertilizers, making them effective for crop production [41,42]. Organic fertilizers have the potential to improve crop growth by providing plant nutrients, as well as improve soil physical, biological, and chemical properties [43–45]. However, they have no enough nutritional content and are also sluggish in releasing nutrients to crops [46–48].

Building sustainable soil fertility management is a long-term process that would require an integration of various soil fertility management practices. Neither organic nor mineral fertilizers alone can ensure the sustainability of soil fertility and productivity [8,49,42]. Especially, in Ethiopia where the use of inorganic fertilizer is one of the lowest due to its expensiveness, and it is also neither crop nor soil-specific, the limited availability of fertilizers may affect considerably the application of integrated soil fertility management approaches [7,28]. One of these soil fertility management practices is the combined use of organic and inorganic fertilizers that can maintain soil's physical, biological, and chemical properties [50–52]. The combination of organic and inorganic fertilizers has been repeatedly reported as the best practice for plant nutrient management, sustainable crop production, and optimizing social, economic, and eco−friendly agriculture [53–55]. The available evidence has shown that the integration of organic manures with inorganic nutrients has met crop plants' nutrient demands. Therefore, a combined application of farmyard manure and inorganic fertilizer causes soil nutrient immobilization and higher plant accumulation [56]. In line with this, many researchers For example [56–59], reported that the combined application of inorganic fertilizers and cattle manure increased the growth, yield, and nutrient uptake of the plants, perhaps through improving soil properties and synchronizing nutrient release for plants.

Recent research findings also reported that the addition of organic materials such as manure could change the phosphorous adsorption and desorption characteristics of the soils [60–62]. Since each manure has distinct qualities, particularly pH and nutrient content, their effects on phosphorus adsorption characteristics and other soil properties also vary. For example, Hafiz et al. (2016) reported that the adsorption intensity of incubated soil was decreased by dairy and goat manure while poultry manure treatments increased it. However, Bahl and Toor (2002) reported a decreased rate of phosphorus adsorption after incubation with poultry manure. Moreover, the total N, P, K, and Ca content of poultry manure was reported to be higher than that of cattle manure [63–65], but it had a higher pH value (alkaline) than FYM [55,58,59]. Similarly, goat manure was shown to have the greatest potassium content when compared to farmyard and chicken manure [59]. Therefore, combining these manures (mixed manure) for their cumulative effects along with blended NPSB fertilizer was hypothesized to change certain properties of Vertisols including phosphorus adsorption, nutrient uptake, and growth parameters of Maize in the greenhouse.

Many studies have analyzed how using a combination of organic and inorganic fertilizers affects the properties of soil, plant growth, and nutrient uptake. For instance [60–62,66], have explored this topic. However, there is no evidence of the effects of mixed manure (cattle, goat, and sheep manures) along with blended NPSB on soil properties including phosphorus adsorption, nutrient uptake, and growth parameters of maize. Therefore, this experiment aimed to investigate the effects of the combined application of mixed manure and blended NPSB fertilizer on selected properties of Vertsisol including phosphorus adsorption, nutrient uptake, and growth of maize under greenhouse conditions. The findings of this research might be utilized to increase soil fertility and crop production.

This study was confined to a greenhouse experiment that involved the analysis of specific soil properties such as pH, organic carbon (OC), total nitrogen (TN), available phosphorus (Av.P), cation exchange capacity (CEC), exchangeable bases, phosphorus adsorption quantity, efficiency, and Freundlich adsorption parameters including adsorption capacity and intensity. The agronomic data collected also focused on the uptake of nitrogen (N) and phosphorus (P), as well as the growth parameters, including height, diameter, and aboveground biomass (AB) of maize.

## 2. Materials and methods

### 2.1. Description of the experimental site

The study was conducted on Vertisol collected from the crop research site of the main campus of Haramaya University, which is located at a distance of 510 km from Addis Ababa in the East direction. The site is located at 9° 26′ N latitude and 42° 05′ E longitude at an altitude of 2001 m above sea level. The mean annual rainfall of the study area was 500–800 mm from 1995 to 2017 with the peak in August (Ethiopian National Meteorology Agency cited in Ref. [67] and the rainfall distribution pattern is a bimodal type. The short rainy season usually starts in March and ends in May, and the long rainy season is between June and September. In 2021, the amount of total annual rainfall was 879.2 mm; with 546 mm during the growing season from sowing to harvest (Fig. 1). The maximum and minimum average temperature ranges during the growing seasons were 22.95 °C and 12.05 °C, respectively (Fig. 1). The major soil type of the study area was classified as Calcic Mollic Gleyic Vertisols (Calcaric, Eutric, Pellic, Chromic) according to the WRB classification system [20,68]. The major food crops grown are cereals (mainly *sorghum bicolor* and *Zea mays*), pulses (*Phaseolus vulgaris*), and vegetables such as *Allium cepa*, *Solanum tuberosum*, *Daucus carota*, *Brassica oleracea*, *shallot*, and *Capsicum*. Intercropping and alley cropping are also common practices in nearby areas [20].

### 2.2. Experimental materials and methods

#### 2.2.1. Experimental materials

Fresh cattle, goat, and poultry manures were collected from the animal farms at Haramaya University. Each type of manure was carefully added into separate pits to initiate the composting process, which lasted for three months. To facilitate proper decomposition, the pits were covered with plastic sheets. Throughout the composting period, the temperature and aeration of materials were closely monitored and managed by turning them every three weeks. Additionally, efforts were made to maintain the moisture content within the ideal range of 50 %–60 %. Upon completion of the composting process, the composted manures were collected from the pits and air-dried at ambient room temperature. Based on their calcium content in, mixed manure consisting of 60 %, 20 %, and 20 % of cattle, goat, and poultry manures was prepared, respectively. The proportion of manures with lower calcium content was increased in the mixture since calcium is the primary cause of phosphorus adsorption. Inorganic fertilizers, including blended NPSB (18.9 % N, 37.7 % $P_2O_5$, 6.95 % S, 0.1 % B) and nitrogen in the form of urea (46 % N), were also used. Maize variety BH661 was used as a test crop.

Fifteen soil samples were collected from the University's Vertisols farmland at a depth of 0–30 cm using an auger in a zigzag pattern. The samples were mixed to make a composite sample. The collected soil samples were air-dried, crushed, and passed through a 2 mm sieve for laboratory analysis and experiment. For soil OC and TN, the size of the samples was further reduced to pass through a 0.5 mm sieve.

#### 2.2.2. Treatments and, experimental design and procedures

The treatments consist of four rates of mixed manure (0, 5, 10, and 15 t ha$^{-1}$) and four rates of blended NPSB (0, 50, 100, and 150

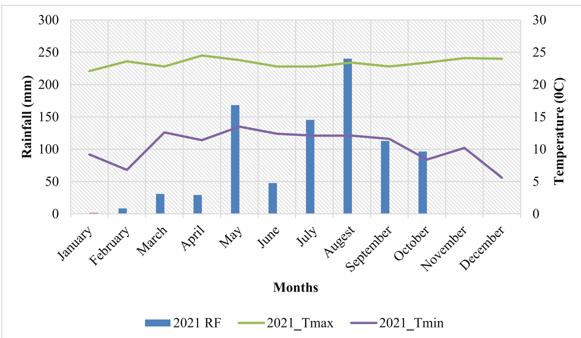


**Fig. 1.** Monthly rainfall (mm) and monthly mean maximum and minimum temperatures (°C) of the experimental site during the 2021 cropping season (source: Jijiga Meteorological Branch Office, Ethiopian National Meteorology Institute).

kg ha$^{-1}$). Thus, the experiment consists of sixteen treatments duplicated three times (Table. 1).

Since the experiment was conducted in the greenhouse by using plastic pots containing 5 kg of soil, the above-mentioned rates of mixed manure and blended NPSB were converted to weight basis (g kg$^{-1}$ of Vertisol) based on soil bulk density (1.2 g cm$^{-3}$) by considering plant root depth of 30 cm. Accordingly, 0, 7, 14, and 21 g pot$^{-1}$ of MM and 0, 70, 140, and 210 mg pot$^{-1}$ of NPSB were used.

The composite soil samples collected from the farmland were mixed with MM according to the intended rates/levels mentioned above and filled into the pots. Subsequently, the pots were tagged and arranged in the greenhouse at 25 °C following a completely randomized design replicated three times and incubated for four weeks before sowing by considering its slow nutrient-releasing nature. After a one-month incubation period, two seeds were sown in each pot along with blended NPSB fertilizer rates on April 17, 2021. All phosphate and half of the recommended rate of N fertilizer were applied at planting time and the remaining half of the N fertilizer rate was applied after 42 days of the sowing period. The recommended rate of inorganic N and P in the experimental area is 100 kg ha$^{-1}$ and 150 kg ha$^{-1}$, respectively [69,70]. Other necessary management activities (weeding, watering, thinning, etc.) were performed.

### 2.2.3. *Soil and manure analyses*

Following maize leaves sample collection, the soil samples were also collected, air-dried, ground, and passed through a 2 mm diameter sieve to determine the effects of treatments on selected soil physical and chemical properties. Soil particle size distribution was analyzed by the Bouyoucus hydrometer method after the soil samples were dispersed with sodium hexametaphosphate [$(NaPO3)_6$] following the procedure described in Ref. [71]. Soil pH was measured potentiometrically in 1: 2.5 soil: $H_2O$ suspension [71]. The organic carbon content of the soil was determined by the wet oxidation procedure of Walkley and Black [63]. The total nitrogen (TN) content of the soil was determined by the wet-digestion procedure of the Kjeldahl method [64]. Available P was extracted by the Olsen method [65] using 0.03M·NH4F and 0.1M·HCl solution and measured calorimetrically by spectrometry. The exchangeable cations (Ca, Mg, K, and Na) and the CEC were determined by extraction with 1M ammonium acetate at pH −7 following the procedure described in Ref. [71]. Calcium carbonate ($CaCO_3$) was also determined using the acid-neutralization method [71].

Manures (cattle, goat, and poultry) composted for three months were air-dried, ground, and sieved with a 2 mm sieve. Electrical conductivity (EC) and pH were determined from a suspension of 1:10 Manure: $H_2O$ as described by Ref. [72]. The OC was estimated by the wet oxidation and rapid titration method [63]. The TN content of the manure was determined by the wet-digestion procedure of the Kjeldahl method [64]. Total P, Ca, Mg, K, and Na were extracted by wet digestion using concentrated sulphuric acid ($H_2SO_4$), selenium (Se) powder, lithium sulfate ($Li_2SO_4$), and hydrogen peroxide ($H_2O_2$) mixture [73]. Total Ca and Mg were determined from the wet digested samples by Atomic Absorption Spectroscopy (AAS) while K and Na were estimated by flame photometer. Total P was determined using a spectrophotometer [73].

### 2.2.4. *Phosphorous adsorption and desorption*

Adsorption study was conducted using the batch equilibrium method [74,75,69]. Plastic bottles of 100 mL capacity were used for each treated soil. To each bottle, 2.50 g of air-dried soil and 25 mL of 0.01 M potassium chloride (KCl) solution containing 0, 10, 20, 30, 40, and 50 mg L$^{-1}$ phosphorus concentration or 0, 100, 200, 300, 400, and 500 mg of P kg soil$^{-1}$ were added to the respective bottle labeled for each P concentration. Three drops of phenol were added to inhibit any microbial growth. The mixtures were shaken for 24 h with a speed of 350 rpm at 25 ± 1 °C and then equilibrated for 30 min. After equilibration, the suspension was filtered through Whatman filter paper No. 42. One control sample with only P in 0.01 M KCL solution (no soil) was also subjected precisely to the same procedure as the test systems to check the stability of the test substance in the KCl solution and its possible adsorption on the surface of the bottles. The P content in the filtrate was determined calorimetrically by a spectrophotometer using the ascorbic acid–molybdophosphate blue method.

**Table. 1**
Treatments and their combinations.

| Treatment No | Treatment combinations |
|---|---|
| T1 | Absolute control (0, 0) |
| T2 | 0 t ha$^{-1}$ MM + 50 kg ha$^{-1}$ NPSB |
| T3 | 0 t ha$^{-1}$ MM + 100 kg ha$^{-1}$ NPSB |
| T4 | 0 t ha$^{-1}$ MM + 150 kg ha$^{-1}$ NPSB |
| T5 | 5 t ha$^{-1}$ MM + 0 kg ha$^{-1}$ NPSB |
| T6 | 5 t ha$^{-1}$ MM + 50 kg ha$^{-1}$ NPSB |
| T7 | 5 t ha$^{-1}$ MM+100 kg ha$^{-1}$ NPSB |
| T8 | 5 t ha$^{-1}$ MM +150 kg ha$^{-1}$ NPSB |
| T9 | 10 t ha$^{-1}$ MM + 0 kg ha$^{-1}$ NPSB |
| T10 | 10 t ha$^{-1}$ MM + 50 kg ha$^{-1}$ NPSB |
| T11 | 10 t ha$^{-1}$ MM +100 kg ha$^{-1}$ NPSB |
| T12 | 10 t ha$^{-1}$ MM + 150 kg ha$^{-1}$ NPSB |
| T13 | 15 t ha$^{-1}$ MM + 0 kg ha$^{-1}$ NPSB |
| T14 | 15 t ha$^{-1}$ MM +50 kg ha$^{-1}$ NPSB |
| T15 | 15 t ha$^{-1}$ MM + 100 kg ha$^{-1}$ NPSB |
| T16 | 15 t ha$^{-1}$ MM +150 kg ha$^{-1}$ NPSB |

The amount of P adsorbed by the soil was calculated from the differences between the amounts found in the filtrate and the initial amount in the solution using equation (1) [70]. Similarly, the phosphorus adsorption efficiency was also calculated using equation (2)

$$Q = (C_o - C_e) \times \frac{V}{M} \tag{1}$$

Where;

Q (mg/kg) is the amount of P adsorbed by the solid phase of soil;

$C_o$ and $C_e$ (mg $l^{-1}$) are the initial and equilibrium P concentration, respectively;

V and M are the solution volume and mass of the soil used, respectively.

$$\text{Phosphorus adsorption efficiency} = \frac{C_o - C_e}{C_e} \times 100 \tag{2}$$

The P adsorption data were fitted into linearized forms of the Langmuir equation (3) and Freundlich adsorption equation (4) separately.

The Langmuir equation can be written in the following linear form [76,77];

$$\frac{1}{Q} = \left(\frac{1}{K_L Q_m}\right) \frac{1}{C_e} + \frac{1}{Q_m} \tag{3}$$

Where $Q_m$ is the maximum P adsorption (mg $kg^{-1}$); $K_L$ is the binding energy constant, with a maximum quantity consistent with higher soil P adsorption. The $Q_m$ and $K_L$ were obtained by regressing $\frac{1}{Q}$ against $\frac{1}{C_e}$. $Q_m$ is the reciprocal of the intercept and the $K_L$ is the ratio of intercept to slope [69,78].

The logarithmic form of Freundlich isotherm model is as follows:

$$\text{Log Q} = \text{Log } K_f + \frac{1}{n} \text{ Log Ce} \tag{4}$$

Where: $K_f$ (L mg$-^{1}$) is the Freundlich adsorption coefficient which represents adsorption capacity whereas n is constant reflecting the adsorption intensity. It is the proportionality constant (mg $kg^{-1}$), $K_f$ = antilog (Y-intercept). The 1/n is the slope of the curve when log (Q) vs. log Ce was plotted.

#### 2.2.5. Plant tissue sample collection and analysis

Just before tasselling, fully grown matured maize leaves were sampled from the middle nodes of each plant randomly and placed in paper bags. The leaves were immediately rinsed with distilled water in the laboratory to remove dirt. When the surfaces of the leaves had dried up, the leaves were placed in paper bags again and oven-dried at 60–70 °C to a constant weight. The dried leaves were ground to pass through a 2 mm sieve and placed in paper bags. Finally, the total N concentration in the leaf tissue was determined by the wet-digestion procedure of the Kjeldahl method [64]. Total P content in the plant leaf was extracted by wet digestion using concentrated sulphuric acid ($H_2SO_4$) and nitric acid ($HNO_3$) and then determined by a spectrophotometer using molybdate and metavanadate for color development as described by Ref. [79].

#### 2.2.6. Growth parameters

Data on growth parameters such as plant height and diameter were recorded during maize leaves sample collection. Plant height was measured from the soil surface to the point where the last leaf started to branch with a meter rod [80]. Stalk diameter was determined by measuring the middle of the first elongated internodes using calipers [81]. Just after the above-mentioned parameters were taken, the above-ground biomass (AB) of maize was harvested and then oven-dried at 60–70 °C to a constant weight. Finally, nutrient uptake was calculated using the following equation (5) [82]:

$$\text{Nutrient uptake} = \text{Nutrient content in the plant tissue} \times \text{AB} \tag{5}$$

#### 2.2.7. Statistical analysis

Data obtained were statistically analyzed using an R-statistical software program (Version 4.0.5) using two-factor analysis of variance (ANOVA) by loading appropriate libraries (readr, ggplot2, multcompView, multcomp dplyr, datasets, and agricolae). The mean comparison was performed using Tukey's HSD test at $p \leq 0.05$. Regression analysis was also used to compare the fitness of adsorption isotherms.

## 3. Results and discussion

### 3.1. Physical and chemical properties of the soils and manures

Selected properties of the experimental soil are presented in Table 2. The textural class of the soil is clay as per the classification of

[83]. The bulk density of the soil falls in the range of 1.2–1.4 g cm-3 which is classified as some too compact according to Ref. [84]. The soil reaction (pH $H_2O$ = 7.76) was in the range of slightly alkaline based on [85] classification.

The organic carbon and total N contents of the soil were low and medium, respectively as cited by Ref. [85]. Available phosphorus was also in the range of medium [76]. The CEC of the soil in the study area was very high according to the rating of [77]. The exchangeable Ca and Mg were also very high, with exchangeable K being high [77]. The calcium carbonate content of the soil was also high (12.5 %) according to the rating of [87] which might be responsible for phosphorus adsorption. Table 3

The results of laboratory analyses of manure from different sources used in the experiment are illustrated in Table 2. The pH value of cattle manure was in the range of neutral while that of poultry and goat manure was alkaline in reactions. The goat manure had a high organic carbon content followed by cattle and poultry, relatively. Poultry manure contained relatively the highest phosphorus, nitrogen, Ca, Mg, and K followed by goat manure (Table 2).

### 3.2. *Effects of mixed manure and blended NPSB fertilizer on soil physiochemical properties*

#### 3.2.1. *Soil pH, organic carbon, total nitrogen, and available phosphorus*

The results of the interaction between mixed manure (MM) and NPSB blended fertilizer on soil pH, OC, TN, and available P are presented in Table 4. The study found that the combined effects of MM and NPSB significantly ($p \leq 0.01$) lowered the soil pH (Appendix Table 1). All treatments except T5 (5 t $ha^{-1}$ MM + 0 kg $ha^{-1}$ NPSB), T7 (5 t $ha^{-1}$ MM + 100 kg $ha^{-1}$ NPSB), T9 (10 t $ha^{-1}$ MM + 0 kg $ha^{-1}$ NPSB), and T10 (10 t $ha^{-1}$ MM + 50 kg $ha^{-1}$ NPSB) shows a lower pH compared to the control. The highest reduction in pH resulted from the treatment that received sole 150 kg $ha^{-1}$ of NPSB. This indicates that the combined application of MM with blended NPSB fertilizers could decrease the soil pH of the study area due to nitrification and humic substance formation during the decomposition of MM. However, the change was still within the same range of classification, which is moderately alkaline [85].

Similar studies conducted by Refs. [88–90] also reported a significant reduction in soil pH as a result of the combined application of animal manure with inorganic fertilizer compared to the control and sole inorganic fertilizer-treated soil. Similarly [91], also found a significant reduction of soil pH by 0.21–0.31 units compared to control treatment as the result of sole as well as combined application of manure with inorganic fertilizer. Such changes may be attributed to the buffering capacity of manure [92–94]. These changes in soil pH affect the solubility and mobility of P in the soil profile by impacting the solubility and adsorption processes of phosphorus-containing minerals [95]. This change may increase P availability to plants.

Soil OC increased significantly ($p \leq 0.01$) due to the interaction effects of MM and blended NPSB (Table 3). All soils treated with rates of MM from 5 to 10 t $ha^{-1}$, as well as their combination with NPSB, revealed significantly higher soil organic carbon except T5 (5 t $ha^{-1}$ of MM + 0 kg $ha^{-1}$ NPSB) in comparison to the control. However, compared to the full dose of blended NPSB (T4), soils treated with sole 10 and 15 t $ha^{-1}$ of MM as well as their combined application with all rates of blended NPSB used for this experiment (50, 100, and 150 kg $ha^{-1}$) showed significantly higher OC content.

Generally, all soil treated with 15 t $ha^{-1}$ of MM and its combined application with each rate applied NPSB revealed statistically highest soil OC content. The observed increase in soil OC content can potentially be attributed to the application rates of MM that contain significant quantities of organic matter. It is important to note that this enhanced soil OC content has crucial implications for soil health and fertility, as well as for environmental sustainability. In line with this result [96], found 55.4 % higher SOC in the soil treated with the combined application of 9.2 t $ha^{-1}$ cattle manure + 130 kg $ha^{-1}$ urea compared to the full dose of urea (322 kg $ha^{-1}$ urea). Similarly [88], also reported the highest SOC from the soil treated with a 50 % recommended rate of NPK (40:20:20 kg $ha^{-1}$) + 50 % decomposed FYM (3.45 t $ha^{-1}$) compared with the control (no fertilizer) and full dose of NPK (80:40:40 kg $ha^{-1}$). Similarly [89], also reported the highest OC in the soil treated with sole 20 t $ha^{-1}$ cattle manure, and also combined application of 15 t $ha^{-1}$ cattle

**Table 2**
Selected physical and chemical properties of the experimental soil in Haramaya district in the eastern highlands of Ethiopia during 2021/22.

| Property | Mean ± sd[1] $_{(n=3)}$ | Rating/class | References |
|---|---|---|---|
| pH | 7.76 ± 0.09 | Slightly alkaline | [86] |
| Organic carbon (%) | 1.18 ± 0.08 | Low | [85] |
| Total nitrogen (%) | 0.099 ± 0.01 | Medium | [85] |
| Available P (mg/kg soil) | 16.6 ± 4.18 | Medium | [76] |
| CEC (cmol$_{(+)}$ mg/kg soil) | 40.0 ± 2.73 | High | [77] |
| Exchangeable cations (cmol(+)/kg soil) | | | |
| K | 0.64 ± 0.07 | High | [77] |
| Ca | 30.2 ± 1.79 | Very high | [77] |
| Mg | 6.16 ± 0.41 | Very high | [77] |
| $CaCO_3$ (%) | 12.5 ± 1.99 | High | [87] |
| Bulk density (g $cm^{-3}$) | 1.24 ± 0.1 | Some too compact | [84] |
| Particle size distribution (%) | | | |
| Sand | 35 ± 1.32 | | |
| Silt | 25 ± 0.50 | | |
| Clay | 40 ± 1.00 | | |
| Textural class | Clay | | [83] |

sd: is the standard deviation; n: is the number of replications. P: phosphorus, CEC: cation exchangeable capacity, K: potassium, Ca: calcium, Mg: magnesium, $CaCO_3$: calcium carbonate.

**Table 3**
Selected chemical properties of manures used for the experiment in the Haramaya district of the eastern highlands of Ethiopia during 2021/22.

| Parameters | Manures | | |
|---|---|---|---|
| | Cattle | Poultry | Goat |
| pH | 6.87 | 8.15 | 8.57 |
| EC (ds m$^{-1}$) | 0.59 | 1.07 | 0.86 |
| Organic carbon (%) | 29.9 | 22.04 | 31.0 |
| Total P (g/kg manure) | 5.58 | 12.8 | 7.26 |
| Total N (%) | 1.73 | 3.50 | 2.27 |
| Mg (g kg$^{-1}$ manure) | 1.23 | 1.50 | 1.36 |
| Ca (g kg$^{-1}$ manure) | 2.14 | 6.68 | 2.19 |
| K ((g kg$^{-1}$ manure)) | 1.14 | 1.97 | 1.73 |

EC: electrical conductivity, P phosphorus, N: nitrogen, Mg: magnesium, Ca: calcium, K: potassium.

**Table 4**
Interaction effects of mixed manure and blended NPSB fertilizers rates on soil pH, OC, TN, and Av.P. in Haramaya district of the eastern highlands of Ethiopia during 2021/22.

| Treatments | | Soil properties | | | |
|---|---|---|---|---|---|
| MM (t ha$^{-1}$) | NPSB (kg ha$^{-1}$) | pH ($H_2O$) | OC *(%)* | TN *(%)* | Av. P *(mg kg soil$^{-1}$)<* |
| 0 | 0 | 7.87a | 0.81ef | 0.04h | 6.96i |
| | 50 | 7.68de | 1.01e | 0.07 fg | 12.31i |
| | 100 | 7.67de | 1.03e | 0.076efg | 21.4h |
| | 150 | 7.62e | 1.13de | 0.08ef | 28.74gh |
| 5 | 0 | 7.87a | 1.01e | 0.05fgh | 21.49h |
| | 50 | 7.66de | 1.30cd | 0.091de | 28.66gh |
| | 100 | 7.86a | 1.27cd | 0.084def | 34.57 fg |
| | 150 | 7.69de | 1.32bcd | 0.091de | 41.83ef |
| 10 | 0 | 7.79abc | 1.27cd | 0.084def | 42.3gh |
| | 50 | 7.80 ab | 1.37BCE | 0.084def | 49.68ef |
| | 100 | 7.72bcd | 1.36BCE | 0.091de | 41.07ef |
| | 150 | 7.70cde | 1.39BCE | 0.098cd | 54.07cd |
| 15 | 0 | 7.69de | 1.47abc | 0.098cd | 63.42b |
| | 50 | 7.68de | 1.64a | 0.112BCE | 62.09BCE |
| | 100 | 7.70cde | 1.55 ab | 0.126 ab | 72.48a |
| | 150 | 7.69de | 1.47abc | 0.13a | 73.82a |
| Sig. level | | ** | ** | *** | *** |
| CV (%) | | 1.43 | 9.71 | 6.53 | 7.33 |
| Tukey's HSD (0.05) | | 0.10 | 0.37 | 0.02 | 9.08 |

Different letters in a column are significant differences between means using Tukey's test at $p \leq 0.05$. HSD (0.05): Honest significance difference at $p \leq 0.05$, CV (%): coefficient of variation, *** Significant at $P \leq 0.001$, ** Significant at $P \leq 0.01$, MM: Mixed manure, NPSB: nitrogen, phosphorus, sulfur, and boron, OC: organic carbon, TN: total nitrogen, Av.P: available phosphorus, Sig.: Significant.

manure with inorganic fertilizers. Furthermore [90], reported 29.8 % and 45.2 % higher soil OC content as the result of integrated use of NPK (N:P: K = 30:26:25 kg ha$^{-1}$) and 4 t ha$^{-1}$ FYM compared to NPK and control treatment, respectively. In addition [47], who investigated the effects of organic manure coupled with inorganic fertilizer also reported a significantly increased soil OC content in the surface layer. Furthermore [97], concluded that there are major advantages to applying inorganic fertilizers in combination with various sources of organic manures in varying amounts to maintain soil nutrient status, increase plant nutrient uptake, and increase maize productivity in cropping systems based on maize.

Similar to soil OC, the soil TN content was also significantly ($p \leq 0.001$) affected by the interaction of MM and blended NPSB rates (Appendix Table 1). All soils treated with each sole rate of MM and blended NPSB, as well as their combined applications except T5 (sole 5 t ha$^{-1}$ MM), had a significantly higher soil TN compared to the control (Table 3). However, compared to the full dose of blended NPSB (T4), soil treated with T12 (10 t ha$^{-1}$ MM + 150 kg ha$^{-1}$ NPSB), T13 (15 t ha$^{-1}$ MM), T14 (15 t ha$^{-1}$ MM + 50 kg ha$^{-1}$ NPSB), T15 (15 t ha$^{-1}$ MM + 100 kg ha$^{-1}$ NPSB), and T16 (15 t ha$^{-1}$ MM + 150 kg ha$^{-1}$ NPSB) had even higher soil TN. The highest TN was observed in T16, which was statistically equivalent to T15. The leading treatment (T16) exceeded the control (T1) and full dose of blended NPSB by 225 % and 62 %, respectively. Overall, increasing rates of MM and blended NPSB considerably enhanced soil TN content in both sole as well as combined treatments, demonstrating that combined application of MM and blended NPSB resulted in superior soil TN content than solo applications of inorganic fertilizer. This higher soil TN content following maize harvest might be attributed to the gradual release of nitrogen during MM decomposition, as well as the lingering effects of blended NPSB. A readily available source of N from mineral fertilizer may increase the mineralization of unavailable organic N forms in manure, resulting in a synergy in which the sum of the parts is better than individuals do.

In agreement with this observation [47], showed a 20 % and 35 % increase in TN in soil treated with an integrated application of 60

% of animal manure (125.8 g $pot^{-1}$) with a 40 % recommended rate of urea (1.56 g $pot^{-1}$) against solitary urea (3.91 g $pot^{-1}$) during the early and late seasons, respectively. Similarly [82], also reported a significantly higher available nitrogen in the soil treated with a combined application of organic and inorganic fertilizer. Furthermore [96], found 38.5 % higher SOC in the soil treated with a combined application of 9.2 t $ha^{-1}$ cattle manure + 130 kg $ha^{-1}$ urea compared to the full dose of urea (322 kg $ha^{-1}$ urea).

The ANOVA clearly shows that the sole rates of MM and blended NPSB, as well as their combined applications, have significant ($p \leq 0.001$) effects on the available phosphorus (Av.P) content of the soil (Appendix Table 1). The Av.P content of the soil increased significantly, as a result of treatments (Table 3). All treatments showed higher Av.P compared to the control, except for T2 (sole 50 kg $ha^{-1}$ NPSB). However, compared to the full dose of blended NPSB (T4), soil treated with T8 (5 t $ha^{-1}$MM + 150 kg $ha^{-1}$ NPSB), T10 (10 t $ha^{-1}$MM + 50 kg $ha^{-1}$ NPSB), T11 (10 t $ha^{-1}$MM + 100 kg $ha^{-1}$ NPSB), T12 (10 t $ha^{-1}$MM + 150 kg $ha^{-1}$NPSB), T13 (15 t $ha^{-1}$ MM), T14 (15 t $ha^{-1}$ MM + 50 kg $ha^{-1}$ NPSB), T15 (15 t $ha^{-1}$MM + 100 kg $ha^{-1}$ NPSB), and T16 (15 t $ha^{-1}$MM + 150 kg $ha^{-1}$ NPSB) demonstrated significantly higher Av.P. Soil treated with T16 showed the highest available P, which was statistically equivalent to T15. The leading treatment (T16) exceeded the full dose of blended NPSB (T4) by 157 %. Generally, as more MM and blended NPSB were used, either alone or in combination, the treated soil's P content displayed a noticeable increase.

The enhanced soil P content may be ascribed to the combined benefits of blended NPSB and mixed manure, which not only supply organic P but also significantly lessen the fixation of applied P in the form of inorganic fertilizer. During its decomposition, manure may release organic acids that compete with $PO4^{-3}$ ions for P retention sites [98,99], and also weaken the stability of fixed/precipitated phosphorus compounds [94]. Furthermore, organic breakdown produces $CO_2$, which generates carbonic acid and solubilizes some primary minerals containing P [100,101]. Our trials also demonstrate the release of more readily available P in the soil treated with a combination of MM and blended NPSB compared to their single applications. These indicate that combined application of MM with blended NPSB could improve the efficiency of applied P in the form of inorganic fertilizer as well as the recovery of unavailable P in the soil in addition to being used as a source of available P. Consistent with this result [102], reported a 43.6 % increase in available content P of the soil through the application of cattle manure compost. Similarly [103], who evaluated the effects of farmyard manure and inorganic fertilizer application on soil physicochemical properties and nutrient balance in rain-fed lowland rice ecosystems also found the highest available P in soil treated by the combined application of 15 t $ha^{-1}$ FYM with 50 and 100 kg $ha^{-1}$ $P_2O_5$. Moreover [47], reported a more than 4 mg $kg^{-1}$ increase in available P content of the soil due combined application of 60 % cattle or poultry manure (125.8 g $pot^{-1}$) + 40 % Urea (1.56 g $pot^{-1}$) compared to the control as well as a full dose of urea fertilizer (3.91 g $pot^{-1}$) during late seasons, respectively.

### 3.2.2. *Cation exchange capacity and exchangeable cations*

The soil's cation exchange capacity (CEC) and exchangeable calcium ($Ca^{2+}$), exchangeable magnesium ($Mg^{2+}$), and potassium ($K^+$) content were found significant due to the combined application of MM and blended NPSB (Appendix Table 1). Compared to the control treatment (T1), all plots treated with sole rates of MM as well as its combined application with blended NPSB had significantly higher CEC including the sole rate of 150 kg $ha^{-1}$ of blended NPSB (Table 5). However, sole rates of 50 and 100 kg $ha^{-1}$ of blended NPSB were

**Table 5**
Interaction effects of mixed manure and blended NPSB fertilizers rates on soil cation exchange capacity (CEC) and exchangeable cations ($Ca^{2+}$, $Mg^{2+}$, and $K^+$) in Haramaya district in the eastern highlands of Ethiopia during 2021/22.

| Treatment | | Soil properties | | | |
|---|---|---|---|---|---|
| MM (t $ha^{-1}$) | Blended NPSB (kg $ha^{-1}$) | CEC(*[cmol(+) (kg soil$^{-1}$])*) | Exchangeable Cations (*$cmol_{(c)}$ kg$^{-1}$*) | | |
| | | | $Ca^{2+}$ | $Mg^{2+}$ | $K^+$ |
| 0 | 0 | 36.16f | 27.57h | 6.9d | 0.60d |
| | 50 | 39.56ef | 30.77fgh | 7.10cd | 0.61d |
| | 100 | 39.17ef | 30.04gh | 7.31bcd | 0.62d |
| | 150 | 41.72de | 32.44defg | 6.91d | 0.64cd |
| 5 | 0 | 46.04bcd | 31.96 fg | 7.35bcd | 0.64bcc |
| | 50 | 44.25cd | 33.51cdefg | 7.29bcd | 0.65bcd |
| | 100 | 44.22cd | 32.31efg | 7.32bcd | 0.65bcd |
| | 150 | 48.16BCE | 34.40bcdef | 7.32bcd | 0.62d |
| 10 | 0 | 46.32BCE | 36.54abcd | 7.95 ab | 0.66bcd |
| | 50 | 47.57BCE | 34.40bcdef | 7.63abc | 0.46bcd |
| | 100 | 46.99BCE | 36.33abcde | 7.65abc | 0.69abc |
| | 150 | 49.91 ab | 36.65abc | 7.79 ab | 0.71 ab |
| 15 | 0 | 54.32a | 39.57a | 7.95 ab | 0.75a |
| | 50 | 52.80a | 37.28abc | 7.91 ab | 0.69abc |
| | 100 | 50.23 ab | 38.55 ab | 7.92 ab | 0.75a |
| | 150 | 52.88a | 37.84 ab | 8.27a | 0.75a |
| Level of Sig. | | * | ** | * | * |
| CV (%) | | 5.47 | 6.28 | 2.97 | 5.97 |
| Tukey's HSD (0.05) | | 7.66 | 6.59 | 0.67 | 0.1 |

Different letters in a column are significant differences between means using Tukey's test at $P \leq 0.05$. HSD (0.05): Honest significance difference at $p \leq 0.05$, CV (%): coefficient of variation, * Significant at $P \leq 0.05$. MM: Mixed manure, NPSB: nitrogen, phosphorus, sulfur, and boron, NS: not significant. CEC: $Ca^{2+}$: exchangeable calcium, $Mg^{2+}$: exchangeable Magnesium, $K^+$: exchangeable potassium.

not varied. The highest value of CEC was observed in plots fertilized with the sole rate of 15 t $ha^{-1}$ of MM which is statistically equivalent to the value recorded in plots fertilized with its combined application of each rate of blended NPSB. The CEC values of the treatments generally increased as the rates of MM increased. Organic residue has a high CEC, so adding MM to agricultural soil can impact the soil's ability to retain and supply essential nutrients to plants [104,105]. In conformity with this result [106,107], found an improved CEC in soil with the combined application of animal manure and inorganic fertilizer. Likewise [98], also reported the highest CEC in plots treated with 60 kg N and 10 t $ha^{-1}$ decomposed manure and other local organic materials. Similarly [89,99], reported an improved soil CEC due to the combined use of animal manure with inorganic fertilizer.

Similarly, exchangeable $Mg^{2+}$ and $K^{+}$ exhibited significantly higher levels in plots fertilized with T11 (10 t $ha^{-1}$ MM + 100 kg $ha^{-1}$ NPSB), T12 (10 t $ha^{-1}$ MM + 150 kg $ha^{-1}$ NPSB), T13 (15 t $ha^{-1}$ MM), T14 (15 t $ha^{-1}$ MM + 50 kg $ha^{-1}$ NPSB), T15 (15 t $ha^{-1}$ MM + 100 kg $ha^{-1}$ NPSB), and T16 (15 t $ha^{-1}$ MM + 150 kg $ha^{-1}$ NPSB) as compared to the control treatment (Table 3). Moreover, T9 (10 t $ha^{-1}$ MM) and T10 (10 t $ha^{-1}$ MM + 50 kg $ha^{-1}$ NPSB) also had higher levels of $Mg^{2+}$ compared to the control treatment. In general, the highest $Mg^{2+}$ and $K^{+}$ content was found in soil treated with 10 and 15 t $ha^{-1}$ of MM, as well as their combined with blended NPSB rates. These increased exchangeable cations may be related to mixed manure, which is a valuable source of nutrients, and organic matter content that in turn retains the nutrients. According to Ref. [108], in manure-treated soil, potassium fixation may decrease while release increases. Organic fertilizer can cause certain soil minerals containing potassium to dissolve due to the decomposition process and the release of organic acids such as fulvic and humic acids, as reported by Ref. [94]. Furthermore, the release of organic acids during the decomposition of manure may generate negative electron charges in the soil with a preference for divalent cations, like, $Ca^{2+}$, and $Mg^{2+}$, leaving $K^{+}$ to be absorbed by negatively charged soil colloids [100]. In line with this result [101], reported a significant increase in exchangeable Mg over the initial status of the soil due to sole 10 t $ha^{-1}$ FYM as well as its combined application with a 100 % recommended rate of NP inorganic fertilizer. Similarly [109,104], also reported a significant increment in soil exchangeable base cations including $Mg^{2+}$ and $K^{+}$ with an increased rate of animal manure application.

### 3.3. *The effects of treatments on phosphorus adsorption characteristics of the Vertisols*

#### 3.3.1. *The quantity and efficiency of adsorbed P*

The interaction effects of mixed manure (MM), blended NPSB, and added P concentration had a significant impact ($p \leq 0.001$) on the quantity and efficiency of adsorbed phosphorus (P) (Appendix Table 2). With the increased rate of added P, the combined application of MM and NPSB significantly increased the quantity of P adsorption in soil (Table 6). This trend was observed in all treatments, with the added P concentration rates ranging from 100 and progressing to 200, 300, 400, and 500 mg $kg^{-1}$. However, the efficiency of P adsorption decreased as the added P concentration consistently increased from 100 to 300 mg $kg^{-1}$ and remained constant as added P increased from 300 to 400 mg $kg^{-1}$ and beyond (Table 5). With each rate of added P concentration, the highest reduction in P adsorption efficiency was exhibited by the soil treated with T16 (15 t $ha^{-1}$ MM + 150 kg $ha^{-1}$ NPSB), while the control

**Table 6**

Interaction effect of mixed manure, blended NPSB, and Added P rates on the amount of phosphorus adsorbed by Vertisols after maize harvest in Haramaya district in the eastern highlands of Ethiopia during 2021/22.

| Treatment | | Adsorbed P (mg kg of soil$^{-1}$) | | | | | Overall |
|---|---|---|---|---|---|---|---|
| MM (t $ha^{-1}$) | Blended NPSB (kg $ha^{-1}$) | 100 | 200 | 300 | 400 | 500 | |
| | | Added P (mg $kg^{-1}$ of soil) | | | | | |
| 0 | 0 | 97.66G | 188.65A | 275.73t | 365.47k | 459.33a | $277.37_a$ |
| | 50 | 96.80G | 185.98ABC | 2.73.9tu | 363.19klmn | 456.99abc | $275.39_b$ |
| | 100 | 94.63GHI | 184.46BCD | 272.37tuv | 360.23no | 441.89g | $270.72_{de}$ |
| | 150 | 93.27HIJ | 184.32BCD | 270.53uvw | 354.73pqr | 439.63gh | $268.50_{gh}$ |
| 5 | 0 | 96.53 GH | 186.65AB | 273.42tu | 364.00klm | 458.01 ab | $275.78_b$ |
| | 50 | 95.36GHI | 183.87BCD | 269.87vwx | 365.11k | 454.16def | $273.67_c$ |
| | 100 | 94.47GHIJ | 183.40BCDE | 266.93xyz | 349.12s | 440.50gh | $266.88_{ij}$ |
| | 150 | 92.65IJ | 183.77BCD | 266.32yz | 352.71qr | 450.90ef | $269.27_{fg}$ |
| 10 | 0 | 95.63GHI | 183.81BCD | 272.42tuv | 361.81lmn | 454.70bcd | $273.68_c$ |
| | 50 | 95.17GHI | 183.22BCDE | 268.80wxy | 360.51mn | 452.13def | $271.97_d$ |
| | 100 | 95.71GHI | 183.36BCDE | 265.91yz | 356.04pq | 437.41hij | $267.68_{hi}$ |
| | 150 | 92.24IJ | 182.82CDE | 265.05z | 352.17rs | 438.54ghi | $266.16_j$ |
| 15 | 0 | 94.66GHI | 178.07F | 270.75uvw | 356.740p | 448.85f | $269.81_{ef}$ |
| | 50 | 94.49GHIJ | 182.08DE | 267.51wxyz | 356.69p | 437.48hij | $26765_{hi}$ |
| | 100 | 92.85IJ | 182.76CDE | 265.55yz | 356.76op | 434.89j | $266.56_{ij}$ |
| | 150 | 91.02J | 180.08 EF | 264.57z | 351.26rs | 436.03ij | $264.59_k$ |
| Overall mean | | $94.57^e$ | $183.58^d$ | $269.37^c$ | $357.91^b$ | $446.34^a$ | |
| Sig. level | | *** | | | | | *** |
| CV (%) | | 3.37 | | | | | |
| Tukey's HSD (0.05) | | 0.35 | | | | | |

Different letters in columns and rows, subscripts, and superscripts show significant differences at $p \leq 0.05$. HSD (0.05): Honest significance difference at $p \leq 0.05$; CV (%): coefficient of variation; MM: mixed manure; NPSB: nitrogen, phosphorus, sulfur, and boron, P: phosphorus, *** Significant at $p \leq 0.001$., Sig. Significant.

treatment (T1) had the lowest reduction.

Furthermore, all treatments with MM and blended NPSB combined applications, had a significantly lower overall mean quantity and efficiency of adsorbed as P compared to the control (T1), (Tables 6 and 7). However, compared to the full dose of blended NPSB (T4), soil treated with T12 (10 t ha$^{-1}$ MM + 150 kg ha$^{-1}$ NPSB), T15 (15 t ha$^{-1}$MM + 100 kg ha$^{-1}$ NPSB), and T16 (15 t ha$^{-1}$MM + 150 kg ha$^{-1}$ NPSB) had a lower overall mean of both the quantity and efficiency of adsorbed P. Soil treated with 15 t ha$^{-1}$MM + 150 kg ha$^{-1}$ NPSB (T16) had the highest reduction in overall mean of adsorbed P. In general, as the rate of MM and blended NPSB increased, the overall mean values of both the quantity and efficiency of adsorbed phosphorus also increased progressively. All treatments reduced the quantity and efficiency of adsorbed P at each rate of the added P concentration compared to the control. However, an integrated application of mixed manure with blended NPSB did more due to their complementary effects in saturation of adsorption site by increasing P solution concentration directly and also changes other soil properties such as pH and organic carbon content that can indirectly affects the capacity of adsorption site. Since composted manure contains negatively charged organic compounds such as humic and fulvic acid [105], its combined application with inorganic fertilizer inhibits P adsorption via site competition. In agreement with these results [110], reported that cattle manure and inorganic P fertilizer application to the soil had a marked negative effect on P sorption and a positive effect on P availability. Similarly, other researchers also reported a significant reduction of P adsorption as the result of composted manure application in agricultural practices [111]. Likewise [112] also reported the successful competition of low molecular weight organic acids produced by the mineralization of animal manure with P for soil sorption, thereby enhancing P mobility in the manured soils. Moreover [113], also reported greater increases in dissolved total phosphorus content in soil treated with treatment with composted manure indicating the reduction of calcium phosphate stability, which is less accessible to plants at alkaline pH. [114] also showed decreased P-sorption efficiency due to the application of poultry, cattle, and goat manure in the P-fixing tropical soil. Therefore, integrating the use of manure with other inorganic fertilizers can improve the bioavailability of P in the soil as well as the efficiency of applied P in the form of fertilizers in P-fixing soils [102,111,115,116].

### *3.3.2. Phosphorus adsorption isotherms and parameters*

The mathematical description of the phosphorus adsorption reactions using Freundlich and Langmuir adsorption isotherms was summarized in Table 8. The data from all treatments were evaluated based on their coefficient of determination ($R^2$), which ranged from 95 to 99 for Freundlich and 91 to 99 for Langmuir indicating that either of the models can be used to describe the data. However, Freundlich isotherm was found to be the best−fit model for all treatments due to its higher coefficient of determination ($R^2 \geq 95$) compared to Langmuir isotherm.

In agreement with this result [117,118], reported that models with $R^2$ larger than 0.9 could be regarded as best suited. This suggests the presence of several adsorption sites or heterogeneous adsorbent surfaces with varying adsorption energies [119,120].

Freundlich adsorption isotherm parameters such as adsorption coefficient ($K_f$) and constant (n) that represent adsorption capacity and intensity were found significantly ($p \leq 0.001$) affected by the interaction effects of MM and blended NPSB (Appendix Table 3). All

**Table 7**

Interaction effects of mixed manure, blended NPSB, and Added P rates on the efficiency of adsorbed phosphorus by Vertisols after Maize harvest in Haramaya district of the eastern highlands of Ethiopia during 2021/22.

| Treatment | | Efficiency of adsorbed P (%) | | | | | Overall |
|---|---|---|---|---|---|---|---|
| MM t ha$^{-1}$ | NPSB Kg ha$^{-1}$ | 100 | 200 | 300 | 400 | 500 | |
| | | Added P (mg/kg of soil) | | | | | |
| 0 | 0 | 97.66a | 94.32fgh | 91.91klmnopq | 91.37nopqrs | 91.86klmnopq | $93.42_a$ |
| | 50 | 96.80 ab | 92.98ijk | 91.33nopqrs | 90.79qrstuvw | 91.39nopqrs | $92.66_b$ |
| | 100 | 94.63def | 92.22ijklmn | 90.79qrstuvw | 90.06vwxyzA | 88.38DEFGHIJ | $91.22_d$ |
| | 150 | 93.27hij | 92.15jklmno | 90.17tuvwxy | 88.69BCDEFG | 87.93FGHIJKL | $90.44_{ef}$ |
| 5 | 0 | 96.53BCE | 93.33ghi | 91.25nopqrstu | 91.00pqrstuv | 91.60mnopq | $92.74_b$ |
| | 50 | 95.63cde | 91.90klmnopq | 90.81pqrstuvw | 90.46rstuvwx | 90.94pqrstuv | $91.94_c$ |
| | 100 | 95.36cdef | 91.95klmnop | 89.96vwxyzA | 91.29nopqrst | 90.83pqrstuvw | $91.88_c$ |
| | 150 | 94.47efg | 91.70lmnopq | 88.98ABCDEF | 87.28JKL | 88.10DEFGHIJKL | $90.10_{fg}$ |
| 10 | 0 | 92.65ijklm | 91.83klmnopq | 88.78BCDEFG | 88.19DEFGHIJK | 90.18tuvwxy | $90.34_{ef}$ |
| | 50 | 95.17de | 91.60mnopq | 89.60xyzABC | 90.13uvwxyz | 90.43rstuvwx | $91.38_d$ |
| | 100 | 95.71bcd | 91.67mnopq | 88.63BCDEFGH | 89.01zABCDEF | 87.48IJKL | $90.50_{ef}$ |
| | 150 | 92.24ijklmn | 91.40nopqr | 88.34DEFGHIJK | 88.04EFGHIJKL | 87.71GHIJKL | $89.54_h$ |
| 15 | 0 | 94.66def | 89.03zABCDEF | 90.26stuvwxy | 89.19yzABCD | 89.77wxyzAB | $90.58_e$ |
| | 50 | 94.49ef | 91.03opqrstuv | 89.17yzABCDE | 89.18yzABCDE | 87.49HIJKL | $90.28_{ef}$ |
| | 100 | 92.85ijkl | 91.38nopqrs | 88.52CDEFGHI | 89.19yzABCD | 86.98L | $89.78_{gh}$ |
| | 150 | 91.02pqrstuv | 90.03vwxyzA | 88.18DEFGHIJK | 87.81GHIJKL | 87.21 KL | $88.85_i$ |
| Overall | | $94.57^a$ | $91.79^b$ | $89.79^c$ | $89.48^d$ | $89.27^e$ | |
| Sig. Level | | *** | | | | | *** |
| CV (%) | | 0.36 | | | | | |
| Tukey's HSD (0.05) | | 1.16 | | | | | |

Different letters in columns and rows, subscripts, and superscripts show significant differences at $p \leq 0.05$. HSD (0.05): Honest significance difference at $p \leq 0.05$, CV (%): coefficient of variation, MM: mixed manure, NPSB: nitrogen, phosphorus, sulfur, and boron, P: phosphorus, *** Significant at $p \leq 0.001$.

**Table 8**
Regression equations and coefficient of determination ($R^2$), indicating phosphorus adsorption data fitness to Langmuir and Freundlich isotherms as influenced by the application of mixed manure and blended NPSB fertilizer rates in Haramaya district of eastern highlands of Ethiopia during 2021/22.

| Treatment | | Langmuir equation | | Freundlich isotherm | |
|---|---|---|---|---|---|
| **MM (t ha$^{-1}$)** | NPSB (kg ha$^{-1}$) | $1/Q = 1/(Q_m K_l)*1/Ce + 1/(Q_m)$ | $R^2$ | $\text{Log } Q = \text{Log } K_f + 1/n \text{ Log } Ce$ | $R^2$ |
| **0** | 0 | 1/Q = 0.0018Ce + 0.0026 | 0.93** | Q = 0.51Ce + 2.29 | 0.97** |
| | 50 | 1/Q = 0.0026 Ce + 0.0024 | 0.93** | Q = 0.57Ce + 2.24 | 0.97** |
| | 100 | 1/Q = 0.0035Ce + 0.0024 | 0.95** | Q = 0.56Ce + 2.17 | 0.98*** |
| | 150 | 1/Q = 0.0064Ce + 0.0014 | 0.99*** | Q = 0.69Ce + 2.10 | 0.99*** |
| **5** | 0 | 1/Q = 0.0029Ce + 0.0022 | 0.95** | Q = 0.59Ce + 2.23 | 0.98** |
| | 50 | 1/Q = 0.0048Ce + 0.0020 | 0.97** | Q = 0.64Ce + 2.12 | 0.99*** |
| | 100 | 1/Q = 0.0048Ce + 0.0020 | 0.98*** | Q = 0.62Ce + 2.13 | 0.99*** |
| | 150 | 1/Q = 0.0076Ce + 0.0013 | 0.99*** | Q = 0.73Ce + 2.06 | 0.99*** |
| **10** | 0 | 1/Q = 0.0037Ce + 0.0021 | 0.94** | Q = 0.64Ce + 2.18 | 0.97** |
| | 50 | 1/Q = 0.0042Ce + 0.0020 | 0.95** | Q = 0.65Ce + 2.16 | 0.97** |
| | 100 | 1/Q = 0.0045Ce + 0.0017 | 0.98*** | Q = 0.65Ce + 2.15 | 0.99*** |
| | 150 | 1/Q = 0.0066Ce + 0.0012 | 0.99*** | Q = 0.75Ce + 2.08 | 0.97** |
| **15** | 0 | 1/Q = 0.0046Ce + 0.0021 | 0.91** | Q = 0.66Ce + 2.12 | 0.95** |
| | 50 | 1/Q = 0.0040Ce + 0.0020 | 0.94** | Q = 0.66Ce + 2.17 | 0.97** |
| | 100 | 1/Q = 0.0061Ce + 0.0014 | 0.99*** | Q = 0.7Ce + 2.08 | 0.99*** |
| | 150 | 1/Q = 0.0084Ce + 0.0010 | 0.99*** | Q = 0.79Ce + 2.00 | 0.99*** |

*** Significant at $P \leq 0.001$, MM: mixed manure, NPSB: nitrogen, phosphorus, sulfur, and boron, Ce: Equilibrium concentration, $K_l$: Langmuir adsorption constant, Q: Quantity/amount of adsorbed phosphorus, $Q_m$: maximum phosphorus adsorption, $K_f$: Freindlich adsorption coefficient, n: Freindlich adsorption constant.

soil treated with either MM or blended NPSB solely or in combinations had lower $K_f$ values than the control group (T1) (Table 9). However, soil treated with T8 (5 t ha$^{-1}$ MM + 150 kg ha$^{-1}$ NPSB), T12 (10 t ha$^{-1}$ MM + 150 kg ha$^{-1}$ NPSB), and T16 (15 t ha$^{-1}$ MM + 150 kg ha$^{-1}$ NPSB) had lower $K_f$ values when compared to the full dose of blended NPSB (4). Treatment T16 had the most notable reduction in $K_f$ value, with 48 % and 21 % as compared to the control group (T1) and full dose of blended NPSB (T4), respectively.

Generally, the $K_f$ value had shown a reduction trend with an increase in the rate of MM and blended NPSB due to the greater affinity of cations for organic products produced from decomposed manure than for $PO_4$. Additionally, this substantial change in $K_f$ value may be also related to the synergistic effects of organic and inorganic P sources in enhancing available P better than their sole application and control to saturate the adsorption sites. Since $K_f$ is considered as capacity (affinity) factor, soil having a larger $K_f$ value has superior

**Table 9**
Parameters of phosphorus adsorption characteristics described with Langmuir and Freundlich equation as influenced by the application of mixed manure and blended NPSB fertilizer rates in Haramaya district of eastern highlands of Ethiopia during 2021/22.

| Treatment | | Langmuir adsorption parameters | | | Freundlich adsorption parameters | |
|---|---|---|---|---|---|---|
| MM (t ha$^{-1}$) | NPSB (kg ha$^{-1}$) | $Q_m$ (mg kg$^{-1}$) | $K_L$ (l mg$^{-1}$) | MBC (L kg$^{-1}$) | $K_f$ (mg kg$^{-1}$)) | n |
| 0 | 0 | 387.72e | 1.41a | 547.75a | 194.15a | 1.96a |
| | 50 | 416.93e | 0.93b | 388.13b | 173.27b | 1.75b |
| | 100 | 418.36e | 0.68cd | 284.39cd | 147.05cd | 1.77b |
| | 150 | 714.1BCE | 0.22fgh | 159.52fgh | 127.28fgh | 1.44efg |
| 5 | 0 | 444.57de | 0.78BCE | 347.14BCE | 170.89b | 1.68BCE |
| | 50 | 497.03cde | 0.42ef | 207.28efg | 133.17ef | 1.57cde |
| | 100 | 498.58cde | 0.42ef | 207.73efg | 134.20def | 1.61bcd |
| | 150 | 777.03 ab | 0.17gh | 135.70h | 114.23i | 1.38fgh |
| 10 | 0 | 476.38de | 0.56cde | 268.06de | 152.36c | 1.57cde |
| | 50 | 489.36cde | 0.49de | 239.54de | 143.78cde | 1.54cde |
| | 100 | 573.52cde | 0.39efg | 212.78ef | 141.42cde | 1.54cdef |
| | 150 | 836.17abc | 0.21fgh | 143.66gh | 119.12i | 1.33gh |
| 15 | 0 | 472.56cde | 0.46de | 216.63def | 132.42efg | 1.51def |
| | 50 | 499.63cdef | 0.5de | 249.40de | 148.86c | 1.52def |
| | 100 | 707.18bcd | 0.23fgh | 151.42fgh | 119.81ghi | 1.43efgh |
| | 150 | 997.06a | 0.12h | 112.60h | 100.75j | 1.27h |
| Level of Sig. | | * | *** | *** | *** | *** |
| CV (%) | | 15.47 | 15.34 | 9.34 | 3.01 | 3.73 |
| Tukey's HSD (0.05) | | 266.59 | 0.23 | 68.44 | 12.85 | 0.07 |

Different letters in columns show significant differences at $p \leq 0.05$. HSD (0.05): Honest significance difference at $p \leq 0.05$, CV (%): coefficient of variation, *** Significant at $p \leq 0.001$, ** Significant at $p \leq 0.01$., MM: mixed manure, NPSB: nitrogen, phosphorus, sulfur, and boron, $K_l$: Langmuir adsorption constant, MBC: maximum buffering capacity Q: Quantity/amount of adsorbed phosphorus, $Q_m$: maximum phosphorus adsorption, $K_f$: Freindlich adsorption coefficient, n: Freindlich adsorption constant.

adsorbing capacity than otherwise. Therefore, the lower mean value of $K_f$ due to the combined application of NPSB and MM indicated that most of the ions present in the system remain in the solution and are available for plant uptake [54]. In agreement with this result [112], found a significant reduction of $K_L$ from 587 to 264 L $mg^{-1}$ as a result of compost manure application. Similarly [115,116], also reported substantially lower $K_L$ due to the presence of higher equilibrium concentration in the soil amended with organic fertilizer as compared to the control. Furthermore [121], also reported lower adsorption of P (less than one-third of applied) in the soil amended with organic fertilizers as compared to inorganic fertilizers in which more than two-thirds of inorganic P of applied P is not available to the plant due to adsorption reaction.

Similarly, the Freundlich adsorption constant (n) of all treatments was found significantly lower as compared to the control (T1) (Table 8). The highest reduction in n value was recorded from T16 (15 t $ha^{-1}$ MM + 150 kg $ha^{-1}$ NPSB) which is statistically similar to T8 (5 t $ha^{-1}$ MM + 150 kg $ha^{-1}$ NPSB), T12 (10 t $ha^{-1}$ MM + 150 kg $ha^{-1}$ NPSB), and T15 (10 t $ha^{-1}$ MM + 150 kg $ha^{-1}$ NPSB). Whereas, compared to the full dose of blended NPSB (T4), which is 150 kg $ha^{-1}$ only soil treated with T16 was significantly reduced in its n value. The leading treatment (T16) revealed a 35 % and 12 % reduction in n value as compared to the control (T1) and a 100 % recommended rate of blended NPSB (T4). The findings of this experiment demonstrate a noteworthy decrease in the Freundlich adsorption constant (n), an indicator of the adsorption intensity or bonding energy, with an increase in the rates of MM and NPSB in each combination. The results reveal that the adsorption efficiency of the specific adsorbent reduces with an increase in the rates of MM and NPSB. This observation suggests that the adsorption capacity of the adsorbent decreases with the increase in the concentration of the adsorbate that saturates the adsorption sites. The study highlights the significance of understanding the impacts of varying concentrations of adsorbate and adsorbent on the adsorption efficiency of the system. In agreement with the result [110], reported a significant reduction of P-binding energy in soil treated with poultry and cattle manure as compared to the control group. Similarly [112], also found a significant reduction of P adsorption intensity from 4.93 to 3.07 as the result of compost poultry manure application.

### *3.4. Effects of mixed manure and blended NPSB fertilizers on maize tissue nutrient content, uptake, and other growth parameters*

#### *3.4.1. Maize nitrogen content and its uptake*

According to the analysis of variance, the interaction effect of mixed manure (MM) and blended NPSB fertilizers revealed a significant impact ($p \leq 0.05$) on the nitrogen content in the Maize tissue and its uptake (Appendix Table 4). All plots that received sole rates of MM, NPSB, or their combinations had higher N content and uptake than the control (Table 10). However, when compared with the full dose of blended NPSB (T4), only plots treated with T15 (15 t $ha^{-1}$ MM + 100 kg $ha^{-1}$ NPSB) and T16 (15 t $ha^{-1}$ MM + 150 kg $ha^{-1}$ NPSB) showed higher content of N in the maize leaves. Likewise, the plots that received T11 (10 t $ha^{-1}$ MM + 100 kg $ha^{-1}$ NPSB), T12 (10 t $ha^{-1}$ MM + 150 kg $ha^{-1}$ NPSB), T14 (15 t $ha^{-1}$ MM + 50 kg $ha^{-1}$ NPSB), T15 (15 t $ha^{-1}$ MM + 100 kg $ha^{-1}$ NPSB), and T16 (15 t $ha^{-1}$ MM + 150 kg $ha^{-1}$ NPSB) showed higher uptake of N as compared to full doze of blended NPSB (T4). In general, soil treated with T15 (15 t $ha^{-1}$ MM + 100 kg $ha^{-1}$ NPSB) and T16 (15 t $ha^{-1}$ MM + 150 kg $ha^{-1}$ NPSB) showed the highest level of N content in maize leaf tissue as well as its uptake. Generally, the leading treatment (T15) which is statistically similar to T16 resulted in 85 % and

**Table 10**
Effects of integrated mixed manure and blended rates on nutrient content and uptake of Maize in Haramaya district in the eastern highlands of Ethiopia during 2021/22.

| Treatment | | TN and TP content | | N and P uptake | |
|---|---|---|---|---|---|
| **MM (t $ha^{-1}$)** | **NPSB (Kg $ha^{-1}$)** | **TN (%)** | **TP (%)** | **N uptake (g $pot^{-1}$)** | **P uptake (g $pot^{1}$)** |
| 0 | 0 | 1.98h | 0.22h | 1.23h | 0.14i |
| | 50 | 2.37 fg | 0.30g | 1.71g | 0.21hi |
| | 100 | 2.71de | 0.42cdef | 2.03efg | 0.32 fg |
| | 150 | 2.89bcd | 0.48cde | 2.35cde | 0.39def |
| 5 | 0 | 2.34g | 0.32g | 1.90 fg | 0.26gh |
| | 50 | 2.56efg | 0.37efg | 2.15def | 0.31 fg |
| | 100 | 2.81cde | 0.50BCE | 2.41cd | 0.43cde |
| | 150 | 3.04BCE | 0.53b | 2.54BCE | 0.44cde |
| 10 | 0 | 2.36g | 0.37def | 2.04efg | 0.32 fg |
| | 50 | 2.69def | 0.44cdef | 2.20cdef | 0.36ef |
| | 100 | 3.07BCE | 0.54b | 2.80b | 0.50abc |
| | 150 | 3.17b | 0.54b | 2.79b | 0.48BCE |
| 15 | 0 | 2.51efg | 0.36efg | 2.25cdef | 0.33 fg |
| | 50 | 3.04BCE | 0.50cd | 2.87b | 0.46bcd |
| | 100 | 3.66a | 0.57a | 3.69a | 0.57a |
| | 150 | 3.55a | 0.55a | 3.38a | 0.52 ab |
| Level of sig | | * | * | *** | * |
| CV (%) | | 3.78 | 5.49 | 4.99 | 7.10 |
| Tukey's HSD (0.05) | | 0.32 | 0.07 | 0.36 | 0.08 |

Different letters in columns show significant differences at $p \leq 0.05$. HSD (0.05): Honest significance difference at $p \leq 0.05$, CV: coefficient of variation, *** Significant at $p \leq 0.001$, ** Significant at $P \leq 0.01$, * Significant at $P \leq 0.05$, MM: mixed manure, NPSB: nitrogen, phosphorus, sulfur, and boron, TN: total nitrogen, TP: total phosphorus.

46 % higher N content, and 179 % and 63 % higher N uptake, as compared to the control and full dose of blended NPSB (T4), respectively.

The higher nitrogen uptake observed in maize can be attributed to the positive synergistic effects of blended NPSB and mixed manure. This combination increases the availability of nitrogen in the soil, as well as improves physical, chemical, and microbiological soil conditions that render more nitrogen available to the maize throughout the growing season. Furthermore, the gradual release of nitrogen from decaying manure provides a consistent source of nutrients, which fosters enhanced nutrient uptake and content. This indicates that farmers can improve the chemical, biological, and physical qualities of the soil by using organic fertilizers, such as farmyard manure, in combination with chemical fertilizers, while also ensuring a reliable, consistent supply of nutrients [122].

The findings of this experiment are consistent with the results obtained by Ref. [98], where the use of inorganic fertilizers with 10 t ha$^{-1}$ of compost made from cattle, sheep, and poultry manure led to a 52.6 % increase in leaf N content compared to the control group. Similarly [62], found that the highest nitrogen content (3.36 %) in plant tissue was observed in a plot that had received a combination of 138 kg ha$^{-1}$N and 10 t ha$^{-1}$ of compost, which was created from animal manure and other local waste in Hawassa Zuria. The same authors also reported the highest nitrogen content in treatments that received 92 kg ha$^{-1}$ N and 15 t ha$^{-1}$ of compost in Meskan.

Moreover [50], reported that applying 3 t ha$^{-1}$ of animal manure along with the full dose of inorganic fertilizer resulted in significantly higher nitrogen uptake in the soil, as compared to using just manure or inorganic fertilizer alone. Similarly [123], found that the nitrogen content of plants increased by 19.8 %–20.7 % than the control group when the recommended rate of inorganic fertilizer was combined with manure. The results reported by Ref. [124] also showed that plants fertilized with a combination of three-fourths of the recommended NPK and half of organic fertilizer had a significantly higher N uptake (54.31 mg plant$^{-1}$) compared to those fertilized with the full dose of NPK (41.80 mg pot$^{-1}$). These findings suggest that combining mixed manure and blended NPSB fertilizer can be an effective strategy to enhance soil properties and promote plant growth.

### 3.4.2. Maize phosphorus content and its uptake

The observed P content in maize tissue and its uptake, which ranged from 0.22 % to 0.57 % and 0.14–0.57 g pot$^{-1}$, respectively, were significantly ($p \leq 0.05$) impacted by the combination of mixed manure and blended NPSB fertilizers (Appendix Table 4). Except for T2 (5 kg ha$^{-1}$ blended NPSB) for P uptake, all treatments exhibited significantly increased contents of P and its uptake than the control (Table 9). However, when compared to the full dose of blended NPSB which is sole 150 kg ha$^{-1}$ blended NPSB (T4), soil amended with T8 (5 t ha$^{-1}$ MM + 150 kg ha$^{-1}$ blended NPSB), T11 (10 t ha$^{-1}$ MM + 100 kg ha$^{-1}$ blended NPSB), T12 (10 t ha$^{-1}$ MM + 150 kg ha$^{-1}$ blended NPSB, T15 (15 t ha$^{-1}$ MM + 100 kg ha$^{-1}$ blended NPSB), and T16 (15 t ha$^{-1}$ MM + 150 kg ha$^{-1}$ blended NPSB) exhibited higher mean values of P concentration in the leaves of maize. However, compared to the full dose of blended NPSB (150 kg ha$^{-1}$ NPSB), soil treated with joint application T11 (10 t ha$^{-1}$ MM + 100 kg ha$^{-1}$ NPSB), T12 (15 t ha$^{-1}$ MM + 100 kg ha$^{-1}$ NPSB), T15 (10 t ha$^{-1}$ MM + 150 kg ha$^{-1}$ NPSB), and T16 (15 t ha$^{-1}$ MM + 150 kg ha$^{-1}$ NPSB) had shown higher P uptake. Overall, the highest P content in the maize tissue and its uptake was observed in the soil fertilized with both treatments T15 and T16, which can be attributed to the synergistic effect of the two fertilizers. This indicated that the combined application of blended NPSB and mixed manure in soil fertilization has been shown to enhance the availability of phosphorus and other related soil properties which could enhance its uptake

**Table 11**
Effects of integrated mixed manure and blended rates on growth parameters and above-ground biomass (AB) of Maize in Haramaya district in the eastern highlands of Ethiopia during 2021/2022.

| Treatment | | Plant growth parameters | | Biomass |
|---|---|---|---|---|
| **MM (t ha$^{-1}$)** | **NPSB (Kg ha$^{-1}$)** | **Height (cm)** | **Stem girth (cm)** | **AB (g pot$^{-1}$)** |
| 0 | 0 | 48e | 1.68f | 62.67g |
| | 50 | 54cde | 1.89ef | 72.22 fg |
| | 100 | 60abcde | 1.97cdef | 78.89ef |
| | 150 | 58bcde | 2.07bcde | 81.33def |
| 5 | 0 | 54de | 1.93def | 81.33def |
| | 50 | 66abcd | 2.11abcde | 84.00cde |
| | 100 | 67abc | 2.09abcde | 85.89bcd |
| | 150 | 60abcd | 2.25abc | 83.89cde |
| 10 | 0 | 57bcde | 2.15abcde | 86.45bcd |
| | 50 | 71a | 2.17abcde | 81.78cdef |
| | 100 | 61abcd | 2.11abcde | 92.22BCE |
| | 150 | 66abcd | 2.37 ab | 88.00bcd |
| 15 | 0 | 61abcde | 2.20abcd | 89.67bcd |
| | 50 | 62abcd | 2.22abcd | 92.22 ab |
| | 100 | 69 ab | 2.28abc | 101.00a |
| | 150 | 63abcd | 2.39a | 95.22 ab |
| Level of sig | | * | NS | ** |
| CV (%) | | 6.98 | 4.96 | 3.79 |
| Tukey's HSD (0.05) | | 12.90 | 0.32 | 9.72 |

Different letters in columns show significant differences at $p \leq 0.05$, HSD (0.05): Honest significance difference $p \leq 0.05$, ** Significant at $p \leq 0.01$, * Significant at $p \leq 0.05$. NS: non-significant. CV: coefficient of variation, MM: mixed manure, NPSB: nitrogen, phosphorus, sulfur, and boron, Sig. Significant, AB: above-ground biomass.

by plants.

The addition of manure to the soil along with inorganic fertilizer has been shown to increase the amount of P available by reducing P adsorption and/or precipitation, increasing the solubility of P compounds, and adding organic P and other beneficial compounds [125]. This practice can also improve the physical and biological environment of the soil, leading to increased P availability and enhanced plant uptake [126,44,96]. This suggests that a combination of organic and inorganic seems to be the most efficient way to meet crop needs for nutrients rather than their sole use, which may have important implications for agricultural practices. In support of these findings [127], revealed that the joint use of organic and inorganic fertilizers resulted in 10.6 %–41.3 % greater concentrations of P in maize leaves as compared to the application of only inorganic fertilizers [50]. also demonstrated that the combined use of 3–6 t ha$^{-1}$ of animal waste with the full dose of inorganic fertilizer resulted in a significant improvement of phosphorus uptake in soil when compared to the use of solely manure or inorganic fertilizers. Similarly [124], observed a substantial increase in phosphorus uptake (82.55 mg plant$^{-1}$) in plants treated with three-fourths of the required NPK and half of organic fertilizer, compared to the full dose of NPK (46.03 mg plant$^{-1}$). Additionally [60], found that the application of 30 t ha$^{-1}$ of bovine dung, 120 kg ha$^{-1}$ of nitrogen, and 92 kg ha$^{-1}$ of phosphorus resulted in 1186 % more maize phosphorus absorption compared to the control. Similarly [125], reported that applying 20 t ha$^{-1}$ of animal manure and 28 kg ha$^{-1}$ of diammonium phosphate in combination positively affected plant growth. These findings highlight the potential benefits of combining mixed manure and blended NPSB fertilizers for improved soil properties and plant growth.

#### *3.4.3. Maize growth parameters and above-ground biomass*

The results showed that the interaction of mixed manure (MM) and blended NPSB significantly affected the select growth parameters of maize such as height, and above-ground biomass (AB), while girth did not exhibit significant variation (Appendix Table 5). The data revealed that all treatments that received a combined application of 5, 10, and 15 t ha$^{-1}$ of MM with each rate of 50, 100, and 150 kg ha$^{-1}$ NPSB resulted in significantly higher maize plant heights than the control group (Table 11). However, no significant variations were observed among sole rates of both MM and blended NPSB. These findings suggest that the combination of MM and blended NPSB can effectively enhance the growth of maize, particularly in terms of height and AB compared to their sole applications.

In agreement with this finding, several studies have supported the notion that combining organic and inorganic fertilizers can lead to an increase in maize plant height. For instance, Ref. [128], found taller maize plants height from treatment that received joint use of 50 % of the necessary nitrogen through an inorganic fertilizer source and 50 % through farmyard manure compared to other treatments. Likewise [129] found the highest maize plant height (175 cm) in soil amended with the combined use of 75 % recommended organic and 75 % recommended inorganic fertilizer as compared to the full dose of inorganic. Similar results were reported by [130, 131,132] who all observed that using a combination of inorganic fertilizers with animal manure can contribute to increased plant height.

However, maize plant diameter showed a significant increase with increased rates of both MM and blended NPSB (Fig. 2). The largest mean values of maize diameter were recorded from the maximum rates of MM (15 t ha$^{-1}$) and blended NPSB (150 kg ha$^{-1}$). This highest diameter may be related to better nutrient availability and uptake. In agreement with this result [131], reported an increased maize stem diameter with increased rates of cattle manure compost with the highest value from 24 t ha$^{-1}$. Similar trends were also reported by Refs. [132–134]. On the other hand, many scholars reported an increased maize plant stem diameter as the result of an increased rate of inorganic fertilizer due to better availability of nutrients in the soil [135–137].

The results of this experiment also showed that the combination of blended NPSB and mixed manure (MM) significantly ($p \leq 0.01$) increased the above ground-biomass (AB) of maize (Table 10). All treatments, except T2 (5 kg ha$^{-1}$ NPSB), had higher AB than the control (T1). Besides these, soil treated with T11 (10 t ha$^{-1}$ MM + 100 kg ha$^{-1}$), T14 (15 t ha$^{-1}$ MM + 50 kg ha$^{-1}$), T15 (15 t ha$^{-1}$ MM + 100 kg ha$^{-1}$) and T16 (15 t ha$^{-1}$ MM + 150 kg ha$^{-1}$) also resulted in higher AB compared to the full dosage of blended NPSB (T4). The maximum AB was achieved with T15, which was statistically comparable to both T14 and T16. This enhanced AB could be attributed to improved soil properties that can increase nutrient availability and uptake by the crop, resulting in overall plant growth and continuous nutrient uptake throughout the plant's developmental stages. The synergistic impact of applying blended NPSB and mixed manure together suggests that the former nourishes the plant during its early phases, while the latter, due to its gradual nutrient release during its latter stages. In conclusion, combining blended NPSB and mixed manure can significantly increase AB, which can be the basis improve crop yield.

Inorganic fertilizers release nutrients quickly during the early phases of growth, whereas organic fertilizers release nutrients slowly and up until the latter stages of development [179, 180]. The findings of this study are consistent with previous studies that have shown the benefits of utilizing organic fertilizers in conjunction with inorganic fertilizers [123]. suggest that the combination of animal manure and inorganic fertilizer resulted in significantly greater dry biomass in maize compared to the use of inorganic fertilizer alone or no fertilizer at all. Similarly [138], reported that the application of NPK (150:85:50 kg ha$^{-1}$) in combination with 7 t ha$^{-1}$ of poultry manure, 8.5 t ha$^{-1}$ of FYM, and 8 t ha$^{-1}$ of sheep manure resulted in higher biological yields of 71.51 %, 66.07 %, and 62.43 %, respectively, compared to the control treatment. These findings are consistent with those of [98,127], who also observed similar outcomes when animal dung was combined with inorganic fertilizer to enhance maize growth performance. It is, therefore, recommended that farmers and agricultural practitioners adopt the practice of combining animal manure with inorganic fertilizer to achieve higher yields in maize production. The findings of these studies offer valuable insights into the potential benefits of combining mixed manure and blended NPSB fertilizers in enhancing the AB of maize.

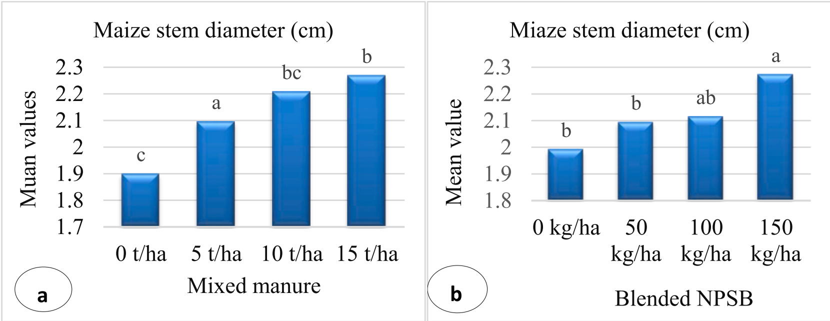


**Fig. 2.** effects of mixed manure (a) and blended NPSB (b) on maize stem diameter in Haramaya district in the eastern highlands of Ethiopia during 2021/2022.

### 3.5. Relationships between selected soil properties, Freindlich adsorption parameters, and maize nutrient uptake

Fig. 3 provides a summary of the correlation analysis conducted between Freundlich phosphorus adsorption parameters, including the adsorption coefficient ($K_f$) representing adsorption capacity and a constant (n) indicating adsorption intensity, and selected soil properties, phosphorus content, and uptake, and the above-ground biomass of maize. The results revealed significant ($p \leq 0.001$) correlations between the Freundlich adsorption coefficient and adsorption intensity and soil properties including organic matter (OM), available phosphorus (Av.P), cation exchange capacity (CEC) contents, and aboveground biomass (AB), phosphorus content (TP content), and its uptake (TP uptake) of maize. The Freundlich adsorption capacity and intensity were negatively correlated with the above-mentioned parameters. Additionally, OM, Av.P, and CEC were positively correlated with the AB of maize, phosphorus concentration in maize tissue, and phosphorus uptake. These findings suggest that amending Vertisol through a combined application of MM and blended NPSB can improve soil chemical properties and Freundlich adsorption parameters, leading to increased availability of phosphorus and its uptake as well as an improvement in the AB of maize.

With the support of these findings [139], reported a negative correlation between the Freindlich phosphorus adsorption parameters ($K_f$ and n) and the availability of phosphorus [140]. also reported a negative relationship between soil organic matter content and phosphorus adsorption capacity due to competition for sorption. Organic matter reduces phosphorus sorption by blocking surface charges on clay or oxide minerals, leading to phosphate desorption and repulsion [141]. Similarly [142] reported a negative correlation between OM added to soil in the form of manure and increased extractable phosphorus for all examined soils. According to Ref. [143], the presence of organic acids, including humic acid, fulvic acid, and citric acid, can impede the adsorption of phosphates. Such organic acids are generated during the decomposition of organic matter and exert their influence through both site competition and electrostatic effects. Therefore, the co-application of animal manure with inorganic phosphate fertilizer is crucial to improve phosphorus uptake and yield of crops [47]. According to Ref. [144], the addition of FYM and NPK resulted in a higher amount of residual P in the soil.

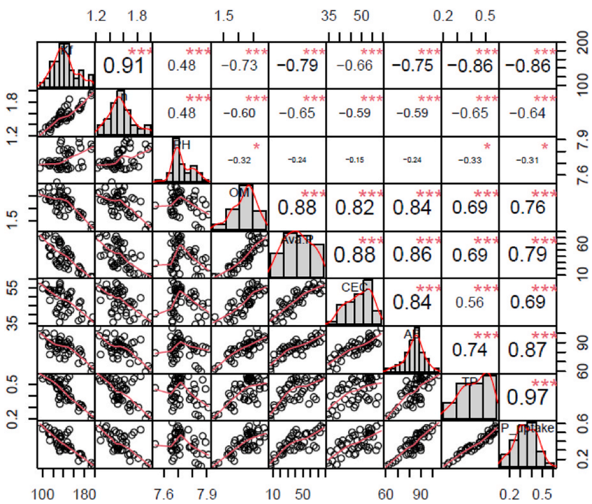


**Fig. 3.** Correlation analysis between selected soil properties, Freindlich adsorption parameters, and maize nutrient uptake.
Note: ***,**, and *: Significant at $p \leq 0.001$, $p \leq 0.01$, $p \leq 0.05$, respectively, $K_f$: Freundlich adsorption coefficient which represents adsorption capacity, n: is a dimensional parameter reflecting the adsorption intensity, OM: Organic matter, Av.P: available phosphorus, CEC: Cation exchange capacity, TP_conc: total phosphorus content, TP_uptake: phosphorus uptake.

However, the study also found that P adsorption was lowest in this soil, suggesting that the application of FYM along with inorganic P fertilizer helped to make the applied P more available and, as a result, reduced P adsorption [145]. also reported that the application of farmyard manure in conjunction with P fertilizer increased plant-available phosphorus throughout the incubation period. This is due to the transformation of stable phosphorus to labile phosphorus and an improvement in the concentration of soil−dissolved organic carbon which competes with phosphorus for adsorption sites. These findings imply that the management of soil organic matter is vital in maintaining soil fertility and ensuring that phosphorus remains available for plant uptake.

## 4. Conclusions

The findings of this study demonstrate that the combination of mixed manure and NPSB inorganic fertilizers significantly improved soil pH, organic carbon, total nitrogen, available phosphorus, cation exchange capacity, and exchangeable. The properties related to phosphorus adsorption, such as adsorption efficiency and Freundlich adsorption parameters, also showed significant improvement with the combined application of mixed manure and blended NPSB mineral fertilizer. Additionally, this combined application led to increased nitrogen and phosphorus concentration in maize tissue and improved growth and yield of maize. The best results were achieved with the application of 15 t $ha^{-1}$ mixed manure and blended NPSB ranging from 100 to 150 kg $ha^{-1}$. These improvements are attributed to the synergistic effects of blended NPSB and mixed manure, enhancing soil chemical features and nutrient availability, which in turn promote maize growth and nutrient uptake. The study suggests that this combined application method can effectively enhance soil properties and promote nutrient uptake, growth, and yield of maize, offering implications for farmers and agricultural experts looking to improve soil fertility and crop productivity sustainably. Finally, the authors recommend further research to analyze micronutrient and sulfur content in the soil, the long-term effects of using mixed manure with straight fertilizers, and determining nutrient concentrations in plant tissue.

## Data availability

All data used in this study are available at https://doi.org/10.5281/zenodo.12719819.

## CRediT authorship contribution statement

**Dejene Teressa:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Kibebew Kibret:** Writing – review & editing, Visualization, Validation, Supervision, Resources, Project administration, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Nigussie Dechasa:** Writing – review & editing, Visualization, Validation, Project administration, Investigation, Data curation, Conceptualization. **Lemma Wogi:** Writing – review & editing, Visualization, Validation, Investigation, Data curation, Conceptualization.

## Declaration of competing interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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## APPENDICES.

**Appendix Table 1**
Mean squares for soil properties after maize harvest as influenced by combined application of MM and blended NPSB in Haramaya district in the eastern highlands of Ethiopia during 2021/22

| Source of variation | df | Mean square | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | pH | OC | TN | Av.P | CEC | $Ca^{2+}$ | $Mg^{2+}$ | $K^{+}$ |
| MM | 3 | 0.07*** | 0.68*** | 0.006*** | 5627*** | 425.6*** | $60.13^{ns}$ | 2.00*** | 0.03*** |
| NPSB | 3 | 0.006*** | 0.14*** | 0.001*** | 559*** | $51.3^{ns}$ | $10.50^{ns}$ | $0.05^{ns}$ | 0.002* |
| MM*NPSB | 9 | 0.013** | 0.02 ** | 0.0002*** | 56*** | $6.4^{ns}$ | $2.70^{ns}$ | 0.14* | 0.001* |
| Residuals | 32 | 0.001 | 0.005 | 0.00003 | 9 | 6.4 | 4.74 | 0.05 | 0.0005 |

Ns = not significant; *, ** and ** = Significant at 5 %, 1 % and 0.1 % probability levels, respectively; $D_f$ = degree of freedom; MM = Mixed manure.

**Appendix Table 2**
Mean squares for quantity and percentage of adsorbed phosphorus as influenced by combined application of MM and blended NPSB in Haramaya district in the eastern highlands of Ethiopia during 2021/22

| Source of variation | df | Mean square | |
|---|---|---|---|
| | | Quantity of adsorbed P | % of adsorbed P |
| MM | 3 | 371*** | 44.81*** |
| NPSB | 3 | 678*** | 69.81*** |
| Added.P | 4 | 924793*** | 241.30*** |
| MM*NPSB | 9 | 26*** | 2.19*** |
| MM:Added.P | 12 | 41*** | 1.66*** |
| NPSB:Added.P | 12 | 105*** | 5.01*** |
| MM:NPSB:Added.P | 36 | 15*** | 1.28*** |
| Residuals | 160 | 1 | 0.11 |

Ns = not significant; *, ** and ** = Significant at 5 %, 1 % and 0.1 % probability levels, respectively; $D_f$ = degree of freedom; MM = Mixed manure.

**Appendix Table 3**
Mean squares for Langmuir and Freundlich phosphorus adsorption parameters as influenced by combined application of MM and blended NPSB in Haramaya district in the eastern highlands of Ethiopia during 2021/22

| Source of variation | df | Mean square | | | | |
|---|---|---|---|---|---|---|
| | | Qm | $K_L$ | MBC | Kf | n |
| MM | 3 | 50656*** | 0.38*** | 49048*** | 2846*** | 0.11*** |
| NPSB | 3 | 371636*** | 0.82*** | 92223*** | 4897*** | 0.23*** |
| MM*NPSB | 9 | $16150^{ns}$ | 0.15*** | 14586*** | 295*** | 0.04*** |
| Residuals | 32 | 9275 | 0.006 | 511 | 18 | 0.003 |

Ns = not significant; *, ** and ** = Significant at 5 %, 1 % and 0.1 % probability levels, respectively; $D_f$ = degree of freedom; MM = Mixed manure.

**Appendix Table 4**
Mean squares for NP concentration and uptake by maize as influenced by application influenced combined application of MM and blended NPSB rates in Haramaya district in the eastern highlands of Ethiopia during 2021/22

| Source of variation | df | Mean square | | | |
|---|---|---|---|---|---|
| | | N. conc. | P. conc. | N uptake | P uptake |
| MM | 3 | 1.19*** | 0.11*** | 2.34*** | 0.11*** |
| NPSB | 3 | 1.06*** | 0.05*** | 3.08*** | 0.09*** |
| MM*NPSB | 9 | 0.03* | 0.002* | 0.08*** | 0.002* |
| Residuals | 32 | 0.01 | 0.0006 | 0.01 | 0.0007 |

Ns = not significant; *, ** and ** = Significant at 5 %, 1 % and 0.1 % probability levels, respectively; $D_f$ = degree of freedom; MM = Mixed manure.

**Appendix Table 5**
Mean squares for growth and AB of maize, as influenced by application, influenced the combined application of MM and blended NPSB rates in Haramaya district in the eastern highlands of Ethiopia during 2021/22

| Source of variation< | df | Mean square | | |
|---|---|---|---|---|
| | | Height | Diameter. | AB |
| MM | 3 | 210.97*** | 0.16*** | 175.2*** |
| NPSB | 3 | 200.47*** | 0.32*** | 1017.2*** |
| MM*NPSB | 9 | 42.10* | $0.01^{ns}$ | 42.3** |
| Residuals | 32 | 18.15 | 0.01 | 10.3 |

Ns = not significant; *, ** and ** = Significant at 5 %, 1 % and 0.1 % probability levels, respectively; Df = degree of freedom; MM = Mixed manure. AB = Above−ground biomass.

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